CHAPTER 3

WATER MANGEMENT SYSTEM OBJECTIVES

Agricultural water management systems may be installed to satisfy a variety of objectives. In most cases, the overall objective is to eliminate water related factors that limit crop production or to reduce those factors to an acceptable level. In the final analysis, the acceptable level depends on the cost of the required water management system in relation to the benefits that will result from its installation. Such benefits vary from year to year with both weather and economic conditions and are difficult to quantify because of the complex interrelationships of crop production processes. The selection or design of an optimum water management system for a given situation may also depend on the land owner. Some owners are willing to operate at a greater level of risk than others, so an acceptable level of drainage protection, for example, may be less for one owner than for another.

As more is learned about modeling plant growth, yields, and machinery-soil interactions (e.g. trafficability), it may be possible to simulate the entire crop production process, and thus to optimize the water management system design based on profit for a given enterprise. Lacking this knowledge at the present time, more intermediate or traditional objectives of water management systems must be used. Such objectives are easier to quantify and generally form the basis for system selection and design. For example, drainage systems in humid regions are usually installed to satisfy two functions: (a) to provide trafficable conditions for seedbed preparation in the spring and harvest in the fall, and (b) to insure suitable soil water conditions for the crop during the growing season. There may be a number of drainage system designs that will satisfy these objectives. For example, a system with good surface drainage and poor subsurface drainage may be adequate while a system with poor surface drainage and good subsurface drainage may serve the same purpose. Whether or not a given system will satisfy the objective depends on the location, crop, and soil properties. Of course, the objective itself may depend on the individual farmer's management capabilities, equipment, and manpower available, etc. For example, one farmer may require 10 working days for harvesting his crop while another farmer may need only 5 days for the same job. DRAINMOD can be used to simulate the performance of a given system design and evaluate the appropriate objective functions for a long period of climatogical record. By making multiple simulations, the least expensive system that will satisfy the water management objectives for a given situation can be chosen.

Four objective functions are routinely computed in DRAINMOD and may be used for evaluating the adequacy of a given system design. These objective functions are:

1. Number of working days - this is used to characterize the ability of the water management system to insure trafficable conditions during specified periods.

2. SEW-30 - stands for sum of excess water at depths less than 30 cm and provides a measure of excessive soil water conditions during the growing season.

3. Number of dry days during growing season - quantifies the length of time when deficient soil water conditions exist.

4. Irrigation volume - when a water management system is designed for land disposal of waste water, the objective function is the allowable amount of irrigation for a specified time interval.

Working Day

A day is defined as a working day if the air volume (drained volume) in the profile exceeds some limiting value, AMIN; if the rainfall occurring that day is less than a minimum value, ROUTA; and if a minimum number of days, ROUTT, have elasped since that amount of rainfall occurred. It should be noted that ROUTA and ROUTT are assumed to be independent of AMIN and of the drainage system. For example, if conditions are very dry, with say an air volume of 150 mm in the profile, a 30 mm rainfall might still postpone field operations for 1 or 2 days even though the soil would normally be trafficable with an air volume of less than 150 - 30 = 120 mm. This is due to the fact that the surface wets up during rainfall and remains too wet for field operations until sufficient time for redistribution of the soil water has elapsed. Values for these limiting parameters are read into the model for two time periods which are specified by the beginning and ending Julian dates. The starting and stopping working hours (SWKHR and EWKHR) are also read in for each period and are used to compute partial working days. For example, let us assume that SWKHR = 0600 and EWKHR = 1800, (i.e., the working day is 12 hours long) for a given period. Then, if rain in excess of ROUTA occurs at 1400 hours, field work would be terminated at that point; and (1400 - 0600)/12 = 0.67 working days would be computed and stored for that day. The parameters AMIN, ROUTA, etc., are dependent on the soil and on the field operation to be conducted. These parameters have been obtained experimentally for some soils and are presented in Chapter 5, along with a discussion of methods for estimating the parameters for other soils.

SEW-30

The concept of SEW-30 was discussed by Wesseling (1974) and Bouwer (1974). It was originally defined by Sieben (1964) to evaluate the influence of high fluctuating water tables during the winter on cereal crops. It is used herein to quantify excessive soil water conditions during the growing season and may be expressed as,

$$\text{SEW-30} = \sum_{i=1}^{n} (30 - x_i) \tag{3-1}$$

Where x_i is the water table depth on day i, with i = 1 being the first day and n the number of days in the growing season. The model actually calculates SEW-30 on an hourly, rather than a daily basis, so the SEW-30 as calculated by the model is more accurately expressed as,

$$\text{SEW-30} = \sum_{j=1}^{m} (30 - x_j)/24 \tag{3-2}$$

Where x_j is the water table depth at the end of each hour and m is the total hours in the growing season. Negative terms inside the summation are neglected. The definition of SEW-30 is shown graphically by the cross-hatched area in Figure 3-1.

The relationship between crop yields and SEW-30 is shown schematically in Figure 3-2. Use of the SEW concept assumes that the effect on crop production of a 5 cm water table depth for a one day duration is the same as that of a 25 cm depth for five days. This seems unlikely as pointed out by Wesseling (1974). The severity of crop injury due to high water tables depends on the growth stage and time of year (Williamson and Kriz, 1970) as well as height of water table and time of exposure which determine the SEW-30 values. Probably, a better method of evaluating the quality of drainage during the growing season is the stress day index (SDI) concept advanced by Hiler (1969). This objective function was used by Ravelo (1977). He used DRAINMOD to evaluate alternative drainage system designs based on predicted excess water damage to grain sorghum. The crop susceptibility factors were defined for 3 growth stages from published experimental data (Howell, et al, 1976) and SEW-30 was used as the stress-day factor. This procedure allowed association of the amount of damage and the level of the stress-day-index. The slight modifications of the model necessary to use the stress-day-index are given by Ravelo (1977). However, the crop susceptibility factors are not available for other crops, so the SEW-30 value is used here as the objective function for quantifying excessive soil water conditions.

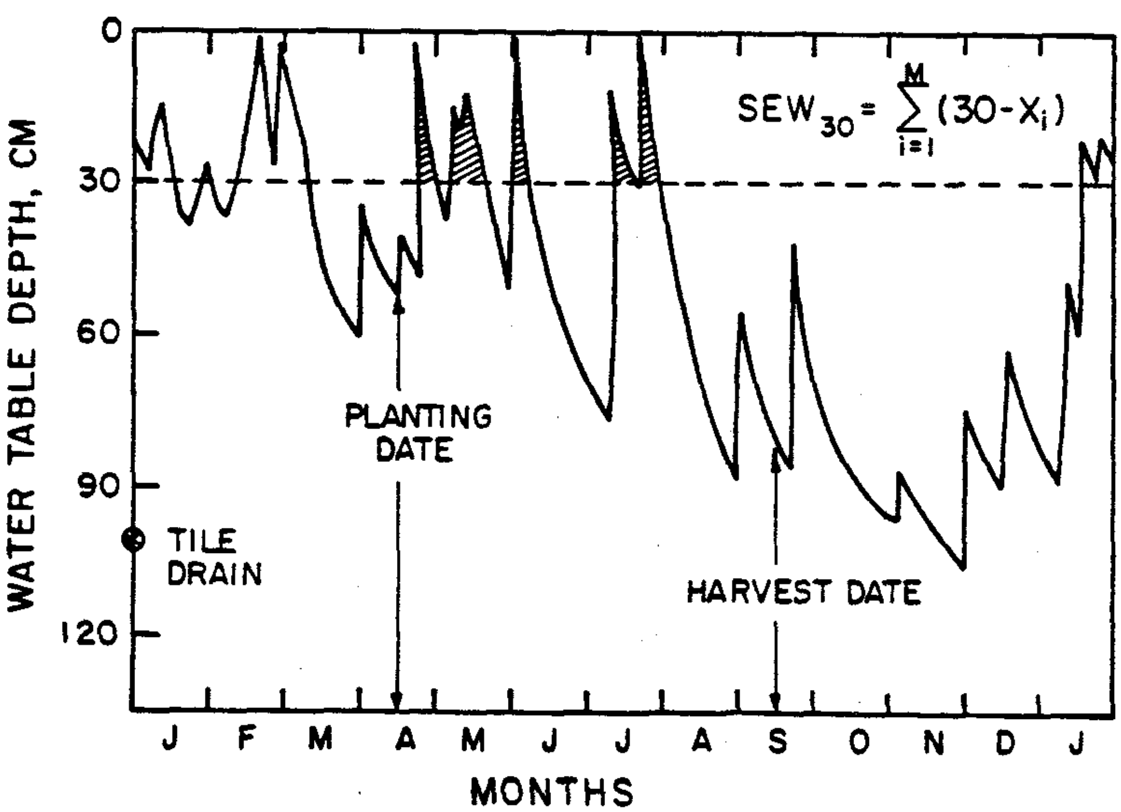

Figure 3-1. SEW-30 may be defined as the area between the water table and a depth of 30 cm (cross-hatched) during the growing season.

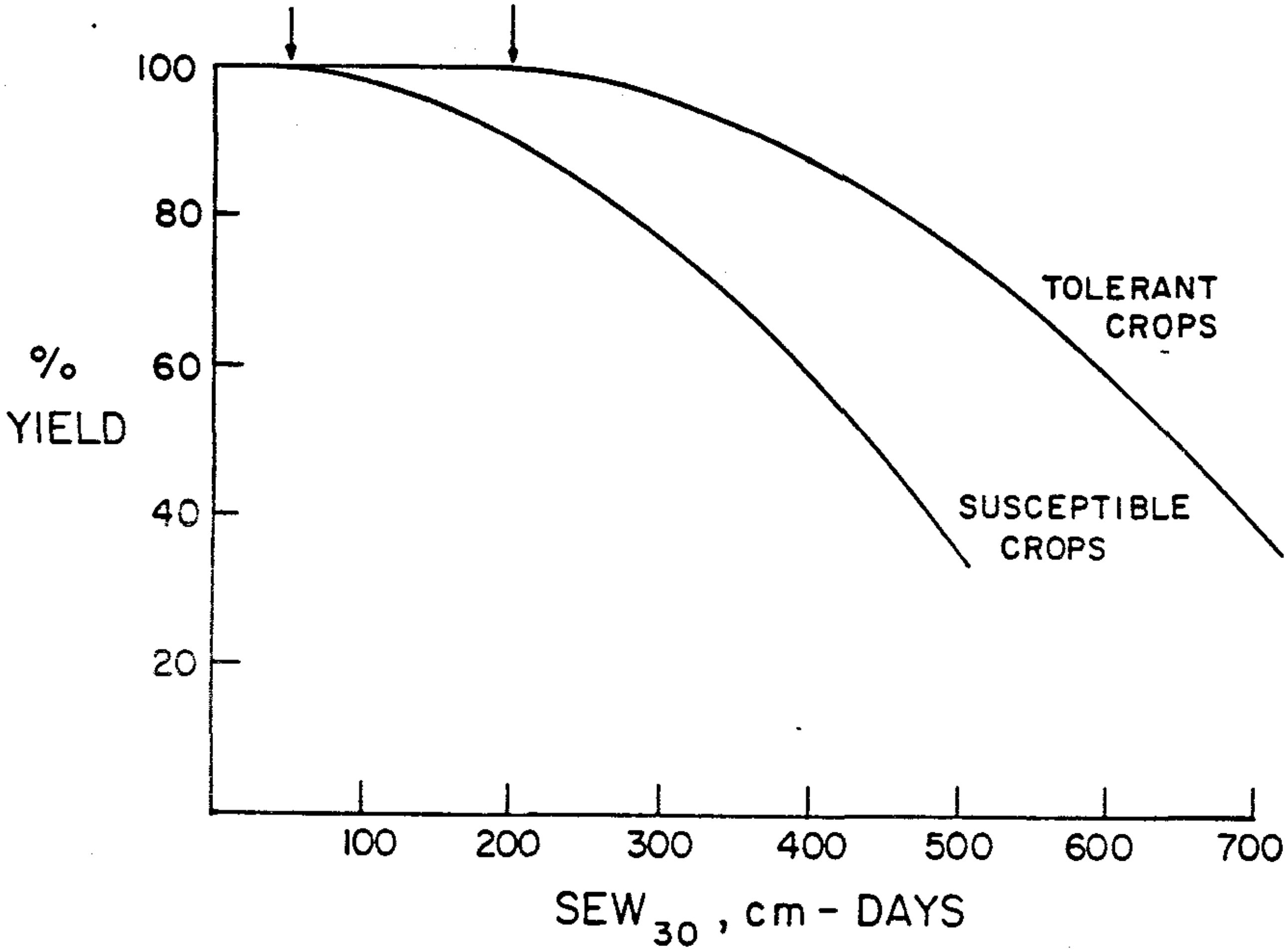

Figure 3-2. Schematic representation of the effect of SEW-30 on crop yields.

Although the SEW-30 concept has a number of weaknesses, it still provides a convenient method of approximating the quality of drainage. Sieben found that yields decreased for SEW-30 values greater than 100 to 200 cm-days. However, his values were calculated for the entire year, rather than just for the growing season as given here. Unless otherwise specified, it will be assumed that drainage is adequate to protect crops from excess water if the SEW-30 value is less than 100 cm-days. Obviously, some crops are more susceptible to poor drainage than others (Figure 3-1), so it may be desirable to adjust the critical SEW-30 value to fit the crop to be grown. Research is currently being conducted to better define the relationship between drainage and crop reponse.

Dry Days

A dry day is defined as a day in which ET is limited by soil water conditions. When the water table is at a shallow depth, water removed from the root zone by ET is replenished by upward movement from the wetter zones near the water table. After the water table is drawn down to a certain depth, the ET demand can no longer be sustained by upward movement alone and the root zone water will be depleted. ET will continue at a rate governed by atmospheric conditions until the soil water content in the root zone reaches some lower limit, $\theta_{\ell\ell}$, as discussed previously. When this condition occurs, ET will be limited to the rate water can move upward to the root zone from the vicinity of the water table. The limiting water content depends on the PET rate, as well as soil and crop properties, although the model assumes that it depends only on the soil (Figure 2-16). Days in which ET is less than the potential (PET) because of soil water conditions are presumed detrimental to optimum crop production and are counted as "dry days." A better method of quantifying stress due to dry conditions is the ratio of actual to potential transpiration, as used by Sudar, et al, (1979). This has not been included in the present version of the model, however.

Thus, the three parameters, working days, SEW-30, and dry days are used to quantify the performance of alternative agricultural water management systems. Ideally, a system would insure a given number of working days during the season when the crops are to be planted; SEW-30 values below a given maximum to prevent crop damage by excessive soil water; and a minimum number of dry days to prevent crop losses due to deficient soil water conditions.

Waste Water Irrigation Volume

DRAINMOD was also developed with the option to evaluate hydraulic loading limitations of land treatment of waste water. Waste water application to the surface may be scheduled at a specified interval, INTDAY, during a given period. If the drained volume in the profile is less than a given amount, REQDAR, irrigation of waste water may be posponed until the next day, at which time the drained volume will again be compared to REQDAR, or it may be skipped until the next scheduled period. If the parameter INSIRR = 0, the irrigation will be skipped. If INSIRR > 0, the irrigation will be postponed until the following day. If rainfall in excess of AMTRN occurs prior to time of scheduled irrigation, it is assumed to be 'rained out' and the event is postponed to the next day. If a scheduled irrigation is postponed more than twice, for whatever reason, it will be skipped until the next scheduled event. When land application systems are hydraulically, rather than nutrient limited, the objective is to apply as much waste water, as possible, without surface runoff. Maximum application reduces the land area required for the system, as well as the size of the irrigation system required. Thus, the objective function for evaluating a system design and irrigation scheme is the amount of wastewater than can be applied per unit area. This function may be evaluated on an annual basis to determine the size of the required system, and on a month basis to assess the waste water storage capacity that may be required during wet months. The amount of water irrigated at each application is read in to the model by specifying the beginning and end times of irrigation, IHRSTA and IHREND, and the application rate for each month AMTSIM (MO) (cm/hr). By specifying a negative value for AMTSIM (I), DRAINMOD will automatically apply the maximum amount of water that the profile will hold at irrigation, less the amount AMTSIM. That is, it will apply an amount TAV + AMTSIM(I) for every scheduled irrigation where AMTSIM(I) < 0.0. TAV is the total air volume in the profile at the time irrigation is scheduled to begin. Normally, a fixed amount of water will be applied at each scheduled irrigation. The option to apply the maximum amount of water that the profile will hold was added to evaluate situations where waste water would be stored during wet periods of the year and then applied at the maximum rate during dry periods.

In addition to determining the effects of a given drainage system design on the amount of waste water than can be applied per unit area of land, DRAINMOD can be used to compare the results of different irrigation strategies. For example, under the guidelines of only applying waste water when runoff will not occur, can more waste water be applied by scheduling two - 1 inch irrigations each week, one - 2 inch irrigation each week or one - 4 inch irrigation every two weeks? It turns out that, everything else being equal, more waste water can be applied by irrigating more frequently with smaller amounts of water. These alternatives are evaluated and discussed in some detail in an example given in Chapter 6.